Technological Forecasting & Social Change 144 (2019) 137–147

Contents lists available at ScienceDirect

Technological Forecasting & Social Change

journal homepage: www.elsevier.com/locate/techfore

Surveying the future of science, technology and business – A 35 year perspective

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ARTICLE INFO

Keywords:
Business futures
Foresight
Planning
Science, technology and society
Innovation

ABSTRACT

We asked readers of *Science*, *Nature* and *Harvard Business Review* about their expectations for advances in science, technology, and business over a 35-year time horizon. We asked further about their needs and dreams for technical products, and their forecasts of converging industries. A fourth survey, fielded later to experts in technology forecasting and science policy, yielded assessments of the earlier survey results as well as the experts' own views on the advances, needs, and convergence questions. A combined analysis of the four surveys leads to this paper's portrait of the expected scientific and business environments 35 years hence, and a description of the gaps between expected developments in science, technology and business on the one hand, and market and social needs on the other hand. Years between 2018 and 2053 will bring significant benefits from the convergence of biomedicine and computer science. They will bring challenges and changes to the agriculture and education sectors. Surveyed experts believe many of the areas of greatest social need, including dealing with climate change, are those that businesses are least prepared to respond to.

1. Introduction and motivation

Innovation plays an important role in modern economic development and business success. It is fueled by progress in science, which provides new knowledge bases for advances in technology. It is useful to business to anticipate the areas where science and technology will make rapid progress. Doing so can support strategy and policy planning for a variety of enterprises in the public and private sectors. Structured attempts at such anticipation fall under the broad heading of foresight.

In this study, we asked readers of *Science*, *Nature*, and *Harvard Business Review* about their expectations for advances in science, technology, and business over a 35-year time horizon. We asked further about their needs and dreams for technical products, and their forecasts of converging industries. A fourth survey, fielded later to experts in technology forecasting and science policy, yielded critiques of the earlier survey results as well as the experts' own views on the advances, needs, and convergence questions.

These surveys address our research questions: What science and technology trends, across a broad variety of fields, will dominate in the next 35 years? What are the gaps between desired products and anticipated sci/tech capabilities, and between the anticipations of educated business persons and those of scientists?

A combined analysis of the four surveys, combined with selected additional data sources, leads to this paper's portrait of the scientific and business environments 35 years hence, and a description of the gaps between expected developments in science, technology and business on the one hand, and market needs on the other hand. This extended expert panel supplements mathematical extrapolations and other (scenarios, Delphi, etc.) methods of apprehending the future.

This study was conducted on the occasion of the 350th anniversary of Merck KGaA, Darmstadt, Germany, the world's oldest pharmaceutical and chemical company. In honor of the anniversary, the company is conducting a series of open innovation activities including a major conference, a new Research Prize, 350 research grants and 350 research challenges. Like the present paper, the anniversary edition of the company's Innovation Cup series is run as an open science activity, with all results released in the public domain to stimulate discussion, to build a global network of innovators.

The results tell a multi-faceted story. Its central thread is that the combination of medical, biomedical, and biotech advances with

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https://doi.org/10.1016/j.techfore.2019.04.005
Received 15 October 2018; Received in revised form 26 February 2019; Accepted 5 April 2019
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developments in artificial intelligence will have the greatest impact on business and society in the next 35 years. Survey participants predict that a golden age for medicine is dawning, along with a multitude of corresponding business opportunities that can lead to formation of entirely new industries and markets. Progress in energy and transportation, both resting on new advanced and sustainable materials, will contribute to human well-being. Companies will consolidate and industries will converge accordingly, even as gaps in attitudes and expectations between businesspeople and scientists and technologists (and between supply of innovations and demand for them) confound matters in the short term. All developments will continue to be subject to funding uncertainties, and to challenges in the food and education sectors.

In following sections, we give a brief background on foresight, explain our study's methodology and its supporting literature, and set forth the results from the four surveys, including respondent characteristics. In a "gap analysis" discussion, we compare the four survey results, highlighting gaps that are of potential importance for corporate planning and public policy. Limitations of the study are noted. A concluding section summarizes key results and management recommendations.

2. Foresight

Foresight has long been a prominent topic in *Technological Forecasting & Social Change*. Rohrbeck et al. (2015a) provide a history of formal foresight and its uses in public and private milieux. Bereznoy (2017) emphasizes the importance of foresight for the strategic management of multinational corporations in a turbulent global business environment. Pietrobelli and Puppato (2016) similarly tie foresight to corporate strategy. Rohrbeck and Gemünden (2011) and Vishnevskiy et al. (2015) clarify the link between foresight and enhanced business innovation.

However, foresight is not just for corporate planning. Georghiou (2008), Durst et al. (2015), and Glenn and Florescu (2017) detail foresight methods and applications for policy and in public agencies including the military.

Prahalad (1998) and Sabatier et al. (2012) focus on the things we don't know that we don't know – what the foresight community calls "wild cards." As we do not know what these are or when they will occur, we see that forecasting is only half the job, the other half being the creation of a flexible and resilient organization able to meet unexpected futures (Linstone, 2011).

Linstone (2011) wrote that what he called the third wave of technology foresight began with the fifth Kondratieff wave downturn. It highlights science at the molecular level, "with nanotechnology, biotechnology, and materials science coming to the fore." It would, Linstone continued, "see increasing evidence of convergence… adopt many concepts from complexity science… and [show] growing concern" for adverse effects of technological advances. These ideas shaped our questions in the surveys; we asked about K-waves, convergence, complex interactions, and technology assessment. Our results corroborate and lend deeper detail to Linstone's framework, with the exception that our respondents expect robotics to take on a bigger role than Linstone anticipated.

Other literature focuses on the challenges of using foresight results in organizations. Thomas et al. (1993) researched businesses' response to and usage of foresight results, as did Rohrbeck et al. (2015b) in telecoms, and Ruff (2015) in automotive industries. Along with Peter and Jarratt (2015), those authors emphasized the thorough diffusion of future-orientation at all levels of the organization. (This orientation complements the "flexibility" that Linstone (2011) and Phillips et al. (2018) and others find important.) While some of the authors strongly advocate top management's commitment to turning foresight results into corporate plans, Thomas et al. (1993) warn that top managers see too much information and cannot commit full attention to everything employees and researchers want them to. Peter and Jarratt (2015) present cases of organizations in which future-orientation became engrained in the culture without top-down direction.

Scientific and technological (S&T) progress over the centuries has been strong in some fields, weaker in others and virtually absent in a few (for example, "orphan diseases") that beg for its benefits (Betz, 2018). Technological advances change business and society. Changes in business and society in turn generate new needs, calling for still further technological solutions (Phillips, 2016). Thus, a foresight project should look beyond S&T indicators (Slaughter, 1996). The usual business indicators (mergers/acquisitions (M&A) and startup activity, stock index movements, etc.) may be used. For lists of social indicators, see United Nations (n.d.), and Stiglitz et al. (2009). As the present study is primarily business-oriented, we subsumed all social indicators, with a few exceptions, under a single variable "social impact." On the business side, we queried respondents about technology convergence-driven M&A activity, and business cycles.

3. Methodology

3.1. Collaborative expert opinions on trends and trend interactions

Popper (2008), Battistella and De Toni (2011), and Sarpong and Maclean (2014) provide authoritative guides to foresight methodology. Our combined analysis of four *expert opinion* surveys was *collaborative*, in that the fourth group provided feedback on the responses of the first three groups. Questions about scientific cross-pollination, technological convergence, and new business combinations required respondents to ponder *interactions of two or more trends.*

Guidance for these features is provided by: Meta-analysis (Hunter and Schmidt, 2004); expert opinion (Pronker et al., 2015); collaborative foresight (Weigand et al., 2014), and trend interactions (Wield et al., 2017).

3.2. Choosing the time horizon

Our choice of a 35-year foresight horizon may seem audacious. None other than Churchill and Spurrier (1931) bit off 120 years in his published musing on the world's condition in 2050.[1] Without doubt, even the span between now and 2052 will be replete with wild cards and black swan events (Popper, 2008; Taleb, 2007). Yet looking ahead 35 to 50 years is not atypical among foresight projects, and our choice of 35 years (a convenient fraction of Merck's 350-year history to date) is in line with this norm. In 2017 the World Economic Forum published their look at the year 2050.[2] Beurle et al.'s (2016) examination of the future of food similarly looks ahead to 2050, as does the Millennium Project (Glenn and Florescu, 2017). The XPRIZE Foundation is currently running a 20-year foresight project,[3] and Sokolov and Chulok (2015) describe a Russian effort that takes on a 30-year horizon.

The rate at which foreseen developments become real depends on funding. Funding forecasts (R&D Magazine, 2016) take a much shorter planning horizon, on the order of two or three years. This increases the uncertainty of science and technology (S&T) foresight, or alternatively forces the foresight project to use multiple scenarios, e.g., reduced funding/steady funding/increased funding.

3.3. Selecting and querying the surveyed populations

Nature and *Science* were chosen as the two global journals with the

[1] http://bigthink.com/the-voice-of-big-think/what-will-life-be-like-in-2050?

[2] https://www.weforum.org/agenda/2017/04/this-is-what-the-experts-think-the-world-will-be-like-in-2050

[3] http://www.iflscience.com/technology/what-do-you-think-the-world-will-look-like-/

highest impact factor covering all aspects of science. HBR Analytical Services was chosen as a partner due to their methodological expertise and *Harvard Business Review*'s reputation in the business field. The readers of these journals are active in their professional fields. They are the people who will create the future described here. For this reason, they were highly appropriate "expert" respondents.

Nature is read by a broad range of scientists; *Science* is also read by scientists, predominantly in biological fields. *Harvard Business Review* is read by business executives, many with a graduate degree in business. (Usually this is an MBA). With few exceptions, the graduate education of an MBA is less technical than doctorates in science and engineering, but business graduates often run the businesses which benefit from technological innovations, or which finance still further innovations.

Each magazine invited all its readers to participate, without compensation. We deemed the resulting responses to be adequate (in number and completeness) for analysis.

Editors of these magazines required the right to make very minor modifications to the questionnaire to suit their distinct readerships and their own data needs. In subsequent paragraphs we note the few instances where this affected our analysis.

There were two rounds of expert surveys. Surveys of readers of *Science*, *Nature* and *Harvard Business Review* were conducted simultaneously, with the cooperation of the journals' publishers. Respondents to the fourth survey were drawn from the editorial board of *Technological Forecasting & Social Change*, the faculty of the Department of Technology & Society at Stony Brook University's College of Engineering and Applied Sciences, and members of the SciSIP[4] listserv. In contrast to the first three surveyed groups, who were practicing laboratory scientists and engineers and business people, the fourth group was chosen for their expertise in S&T policy and in technology forecasting. The fourth survey used a refined set of questions closely similar to those in the earlier surveys, and in an additional section, gave respondents the opportunity to comment upon the responses from surveys 1 through 3.

The respective magazine publishers agreed to cooperate subject to being able to collect additional information for their own purposes. Topic coverage and question wording was therefore only (roughly) 85% identical across the *Science*, *Nature*, and *HBR* surveys. *Science*, *Nature* and *Harvard Business Review* own the copyrights to their questionnaires. We are able to share the forecasting expert survey questionnaire as an "supplementary file" with this paper.

4. Survey results

4.1. Respondent characteristics

795 respondents completed the *Science* survey between April 25, 2017 and May 8, 2017. The responding sample sizes from *Harvard Business Review* was 1000, from *Nature* 360, and from the fourth survey (which is presented in its own section farther below), 117.

As *Science* is published in the USA and *Nature* in the UK, 55% of *Science* respondents live in USA and Canada (with Europe, Asia/Pacific, and Latin America represented by 19%, 15% and 7% respectively), and 41% of *Nature* respondents live in Europe (with 30% hailing from USA and Canada). In both the *Science* and *Nature* surveys, the plurality of respondents works in biosciences. A fair number work "across disciplines." *Nature* respondents skewed toward younger ages.

We detail place, seniority, and occupational profiles of all four survey's respondents.

4.2. Geographic origins

The *Harvard Business Review*, *Nature*, and *Science* had their survey respondents from all global regions. The *Harvard Business Review*'s survey included a roughly proportionate number of participants from North America, Europe, and Asia, with representations of 34.9%, 30.5%, and 28.2%, respectively. The *Nature* survey had a larger number of participants from Europe at 46.90%, with North America at 24.40%, and Asia at 18%. The *Science* survey included 54.3% of participants from North American, 18% from Asia, and 19% from Europe.

Although the *Harvard Business Review* respondents were evenly distributed between North America, Europe, and Asia, nearly half (46.9%) of *Nature* participants were from Europe, while slightly more than half (54.30%) of *Science* respondents were from North America. The unique geographical makeup of the respondents shed light on possible comparisons between European dominant scientists and North American dominant scientists.

Thirty-eight forecasting/policy expert survey participants live in North America, 24 live in Europe, and 10 in Asia. As in the other surveys, Asia included Middle East, and North America included Central America and the Caribbean.

4.3. Age spread

The age of respondents from the *Science* survey was evenly distributed among each age bracket. However, in the *Harvard Business Review* survey, there was a higher number of participants in the 45 to 54 age group.

Clearly, many respondents will be alive 35 years hence and many will not. Older respondents to our surveys express needs and dreams for health-related items; younger ones for gadgets. The younger ones will be older in 2052, presumably concerned then with health and longevity. What the youngsters of 2052 will dream, is anyone's guess.

4.4. Specific job categories

The *Harvard Business Review* survey asked participants about their working industries. Out of the 1000 *Harvard Business Review* survey respondents, the top three industries most represented were *Management Consulting* with 150 participants; *Educational Services* with 83 participants; and *IT Consultancy/Services* with 60 participants.

By contrast, the *Nature* survey directly asked respondents their job titles. Out of 360 total participants, there were eight research directors or vice presidents of research, 16 technicians or research assistants, six physicians or clinicians, six healthcare professionals, 10 principal investigators, 32 research scientists, 67 students, 21 post-doctoral students, 44 professors, 87 PhD or Masters students, and 61 in the interdisciplinary category who did not match any of the previously mentioned job titles. Therefore, 219 of the *Nature* survey participants were from academia.

Similarly, *Science* asked its participants about their primary organizations they work or study. Of 795 total participants, 417 were in academia, 26 worked in biotech or pharma, 50 were consultants, 62 worked for the government, 44 worked at hospitals or clinics, 76 worked at nonprofit organizations, 80 were retired or emeritus, and 40 were classified as interdisciplinary and did not associate with the previously mentioned organizations.

Out of 76 participants in the forecasting/policy experts survey, the majority was from academia: *Professors* (50), *Postdocs* (3), *PhDs or Masters* (1), *Students* (1), totaling 55 of 76 (72.36%). There were thirteen research-related professionals that included *Research Scientists* (5), *Research Director or VP of Research* (4), *Principal Investigator* (3), *Laboratory Director* (1). In contrast to our other surveys, there were no healthcare professionals or medical doctors.

5. Analysis

Because the samples were not random – each magazine used its own opportunity sampling method, and the fourth survey was for all

[4] Science of Science and Innovation Policy.

practical purposes a census of the *Technological Forecasting & Social Change* editorial board – analysis of the quantitative responses is restricted to descriptive statistics. Qualitative responses to the "dream product" questions were analyzed using the QDA package.[5]

5.1. Science advances

Each survey asked participants to indicate which science area would have the greatest potential for breakthrough discoveries in the next 35 years.

Percentages in Fig. 1 may exceed 100% due to respondents' multiple selections of, e.g., subfields of biology.

The consensus areas across the surveys, concerning the top three most breakthrough-prone science areas, were medical science, biological science, and computer science. This result is consistent with the broad inclusiveness of these three categories, and the current momentum of advances in all three. However, respondents were aware of the diverse sub-fields within each of the three, and more nuance emerges in subsequent sections of this paper.

5.2. Technology advances

Each survey also asked participants to predict which technologies would have the biggest impact in the next 35 years. Respondents believe technology advances will follow top scientific advances in the same fields.

Again, multiple selections in sub-fields lead to the high percentages in Fig. 2, as e.g., biotechnology includes synthetic biology and genetic engineering technologies.

Although there was consensus between scientists and business respondents about science breakthrough, there was divergence between them about technology. While 52% of *Harvard Business Review* (HBR) respondents anticipated that Space Travel technologies would have the *biggest impact on society* in the next 35 years (followed by new sources abundant energy, 45%, and synthetic biology/genetic engineering, 36%), *Nature* and *Science* respondents did not consider Space Travel to be an influential technology in the next 35 years. The difference could be due to high-profile investment opportunities now arising in the private sector around space technology.

What technologies do respondents *not* expect to see in 35 years? *HBR* readers expressed most doubt about commercial space stations, a secure internet, and reversing the effects of climate change. (*Science* and *Nature* readers were not asked this question.)

5.3. Progress in industrial sectors

Nature survey participants were asked to anticipate which business sector would see the most development over the next 35 years. The top three sectors expected to show greatest future development in the next 35 years were, in order, Biotechnology, Information Technology (IT) and Software, and Energy.

The *Science* survey asked its respondents to similarly predict which industries would experience the most future development. Biotechnology industry received the most votes. The Energy sector came in second, followed by Robotics. IT/software came in fourth, and Healthcare fifth.

Two items on the *HBR* survey pertained to this question. The first was "Which of the following innovation breakthroughs do you believe would have the greatest impact on society and industry during the next 35 years?" The top three replies were: Nearly complete reliance on solar, wind and other sources of renewable energy; Agricultural and economic innovations that provide food to nearly the world's entire population; and Medical breakthrough for curing cancer. The second question (open-ended) was "In your opinion, what types of potential new industries will emerge in the future given expected developments and convergence in science and technology?" *HBR* readers most expected new industries to grow around (1) energy, (2) medicine, and (3) biotech. (If medicine and healthcare are combined, they jump to #1.) Runner-ups were data management and robotics.

Questions in the three surveys addressed the same topic – business development – but were not worded identically. As answers are not strictly comparable, we do not display them in a graph.

5.4. Dream products

The three reader surveys asked participants which products they would like to see developed within the next 35 years. Answers reflected personal desires and perceived social needs. The *HBR* survey drew 532 responses to this question (53.2% of total respondents), while *Nature* drew 199 (55.3%) and *Science* 658 (82.7%). Table 1 shows their top answers.

The Medicine category swept the key words "cure or treatment or medicine or medication or antibiotic or vaccine or stem or cell treatment or gene therapy." It also included medical implants/devices, "brain chip implant" or "medical diagnostics on a chip" from *Science*. Furthermore the Medicine category included answers from *Harvard Business Review* respondents describing futuristic medical robots or automatic body monitoring, for example, "medical robots like advanced artificial limbs that are more powerful than natural limbs to take programmable orders from computers" or "automatic body monitoring medical treatment for childhood diseases," "Crop enhancing techniques to feed the entire world," "Regrow my lost hair," and "Automated human operation (medical) machines," or "Medical check up & automatic treatment." *Science* participants mentioned advanced cancer therapy such as "T-cell therapy for cancer."

The Energy category is built from key words as "fusion or energy or solar or planet or renewable or clean or alternative" to detect any alternative or clean energy answers, numbering in total 290. Some answers include "Solar panel converting nearly 100% of solar energy" from *Science* and "Colonization of Space," "Human organ manufacturing," and "Completely solar powered world" from *Harvard Business Review;* "Cheap solar energy, driverless cars, flights to Mars," from the forecasting experts, and "Controlled nuclear fusion. It is clean and safe" from *Nature*.

The Agriculture category used key words "food or vegetable or eco-friendly or water or environmental friendly or nutrition." From *HBR*, there were "food replication products such as 3D printing on demand," "water resource eternally refilling," and "World-wide sustainable source of food," and "Nutrition pills to replace food".

The Artificial Intelligence or Robots category showed answers from *HBR* such as "Advanced robotic/AI systems for care of elderly at home" and "Brain-computer interface, Predictive Healthcare (step beyond preventive), Decentralized internet". Answers from *Nature* included "Molecular computing/Quantum computing/Information teleportation/Carbon nanotubes based structures" and "brain-computer interface plus robotic device."

For the Space or Space travel category, *HBR* respondents wished for "A time travel machine," "A machine to transport you anywhere instantaneously," and "The hyperloop which will cut down travel time." "Interstellar travel vehicles." "Driverless vertical take off and land public taxis." Other ambitious answers were "Rockets that can get to Mars in weeks instead of years" from *Science* and "Teleportation. Space travel. Body parts regeneration. Body modification/enhancement. Cybernetic organism" from the forecasting experts.

Table 2 summarizes the keywords used in the text analysis. Fig. 3 details the responses in each category from participants in each of the four surveys.

The agreement across the three magazine reader groups is notable.

[5] https://provalisresearch.com/products/qualitative-data-analysis-software/freeware/

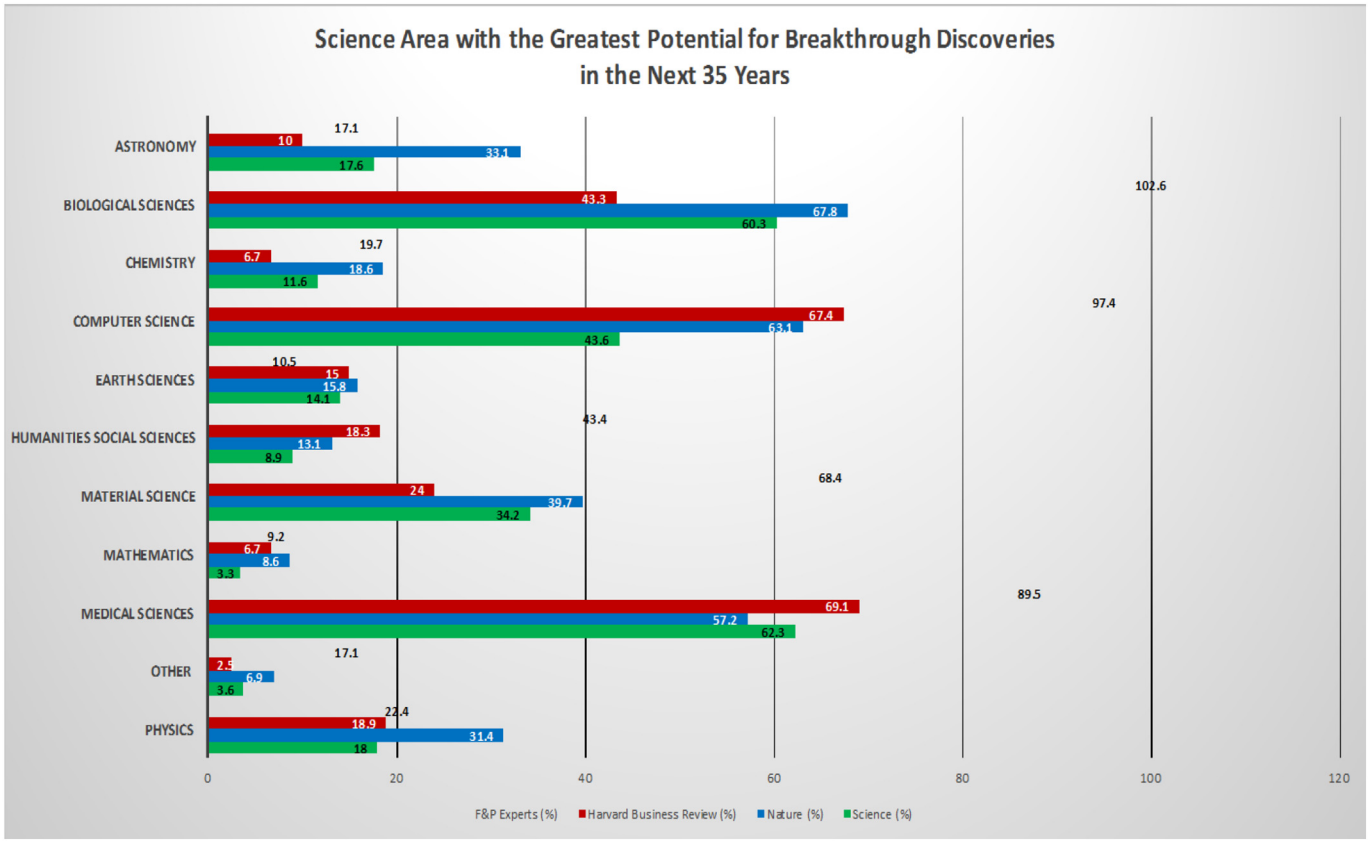

Fig. 1. Percent of respondents naming each science area most likely for breakthrough discoveries in 35 years.

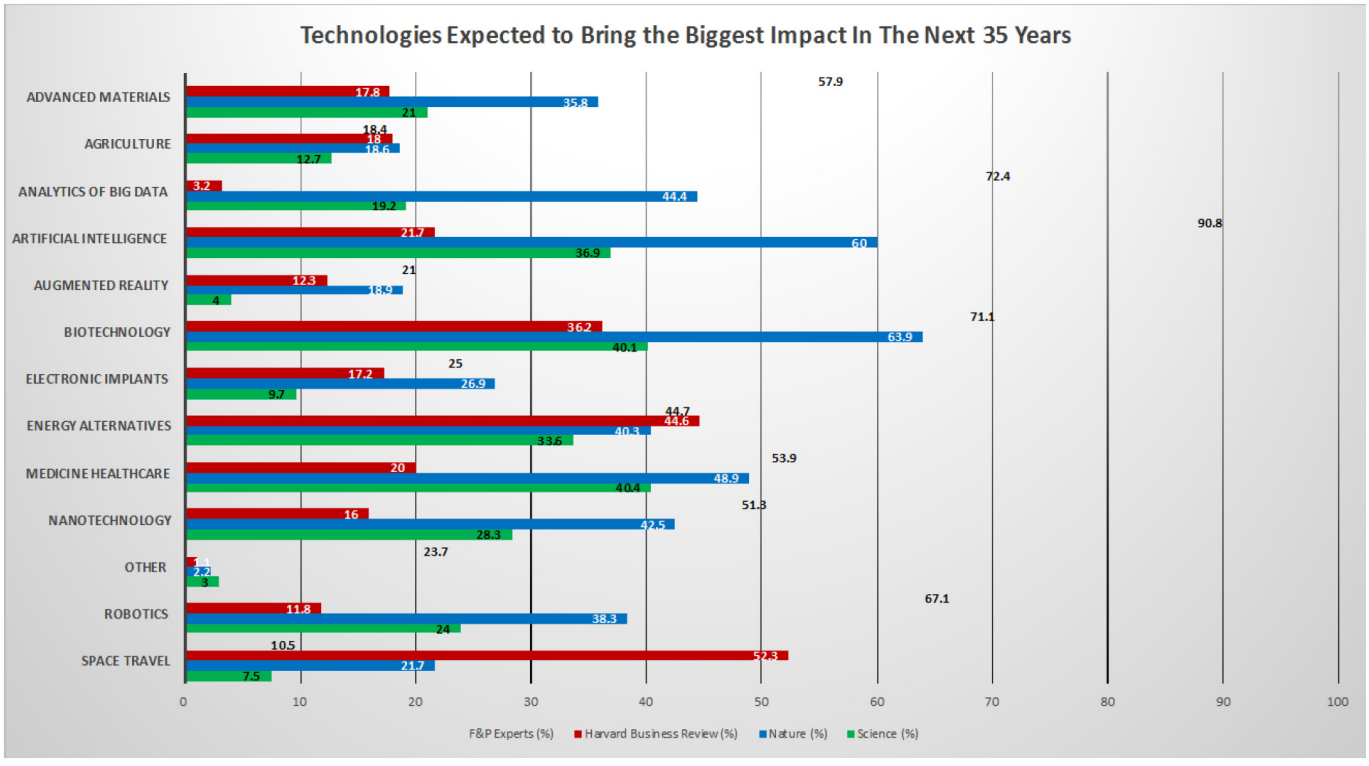

Fig. 2. Percent of respondents naming each technology area likely to have most impact in 35 years.

Table 1
Top desired products for next 35 years, 3 reader surveys.

Science	Nature	Harvard business review
New modes of transport	Biotechnology products	New modes of transport
Providing clean, abundant energy	Providing clean, abundant energy	Alternative energy
Medicines for diseases not yet conquered	Medicine/Healthcare	Medicines for diseases not yet conquered

Table 2
Construction of qualitative analysis categories, "dream products".

Key words(using or)	Categories	QDA counts
Drugs, cures, treatment, disease, pharma, Vaccine Alzheimer, Brain, antibiotic	Medicine	273
DNA, stem, RNA, genetics, genomics, biomarker, cell therapy	Biotechnology	44
Nano robots, Quantum computers, Artificial Intelligence, Computer, Data Analytics	AI (computer, data, robots)	147
Virtual reality, Augmented Reality	Augmented reality (Virtual reality)	16
Airplane, automobile, vehicles, cars, transport, uber, lyft, driverless, hyperbole	Transportation	50
Food, water, vegetable, agriculture, environment	New agricultural products	135
Material, texture, invisible, cloak	Advanced material	10
Fusion, energy, solar, planet, renewable, clean, alternative	Energy (Renewable, clean, alternative)	290
Mars colonization, Moon, space, Space Travel, time travel	Space (Travel)	75
Implant, organ, limb, arm,		13
Learning or education or school	Education	38
Health or Healthcare system	Healthcare system	14

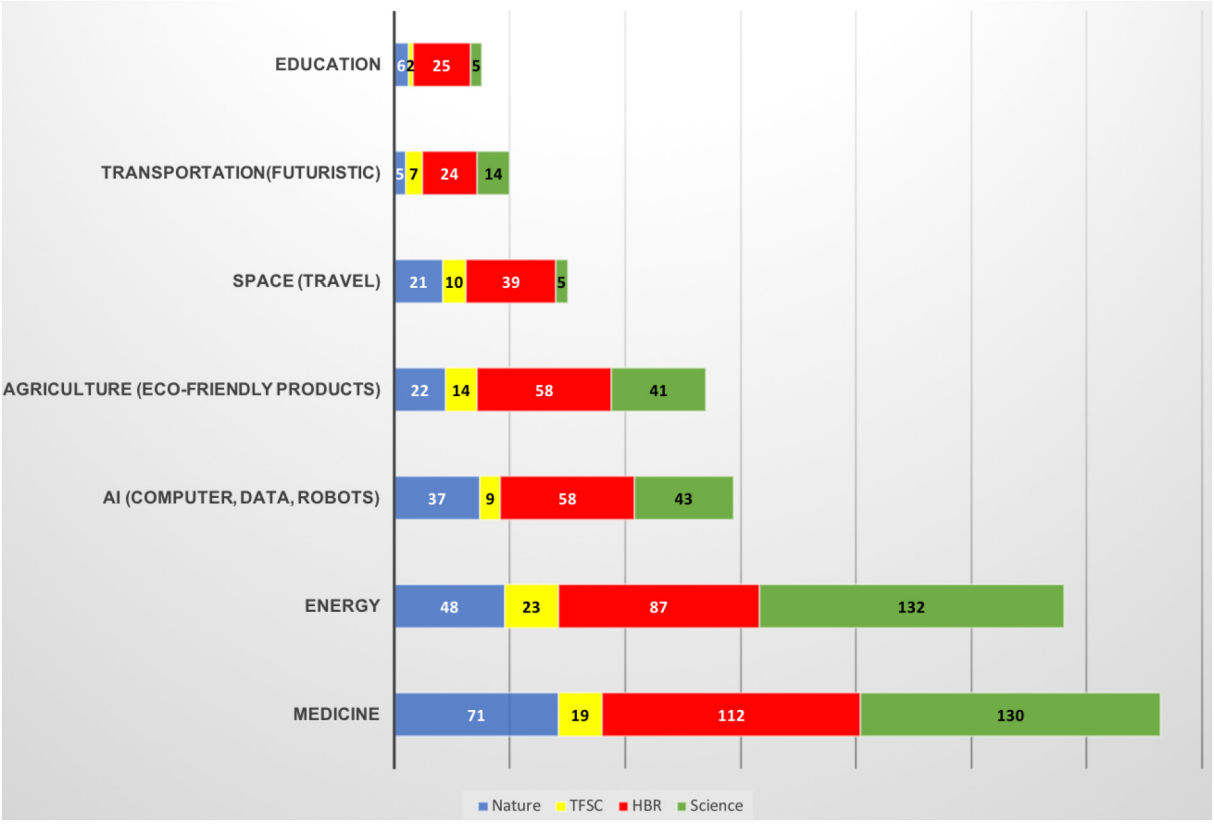

Fig. 3. "Dream product" areas mentioned by participants in four surveys. (The forecasting/policy expert survey is abbreviated "TFSC" in the graph.)

The forecasting/policy experts disagreed with the readers, on the matter of medical products.

A complete list of the free-form "dream product" responses is in Appendix I.

6. Survey of forecasting and policy experts

The authors conducted a fourth foresight survey. Targeted respondents were experts in technology forecasting and/or technology policy.[6] This group were asked additional questions, inspired by our

[6] Respondents were (1) members of the editorial board of the journal *Technological Forecasting & Social Change* (TFSC); (2) members of the SciSIP (Science of Science & Innovation Policy) listserv; and (3) members of the Technology & Society Department faculty at Stony Brook – State University of New York.

Table 3
Top anticipated areas, forecasting/policy expert survey.

Science breakthroughs	Technology breakthroughs	Business development areas	Dreams and needs
Biological sciences	Artificial Intelligence	Robotics	Alternative Energy
Medical sciences	Big Data Analytics	Biotechnology	Space Travel
Computer sciences	Biotechnology	Energy	Robots

examination of the first three surveys, as well as the questions asked to the first three groups.

Respondent's primary study or work area were Social Sciences or Humanities (20 people), Interdisciplinary (19), Management or Business (16), with the remainder coming from Computer Science/Engineering, Biological/Biomedical/Physical Sciences, or (11 people) "Other." Because this survey was formulated and fielded following our inspection of the first three surveys' results, we present it in this separate section of the paper, and summarize topline results in Table 3.

Anticipating progress in *science* areas, the expert participants forecast scientific breakthroughs as most likely in Biological Sciences, Medical Sciences, and Computer Sciences. Material Sciences was a "runner-up" mention.

Asked to list the advances least-expected or "impossible" within 35 years, they named a unified field theory; translation of models from quantum to macroscopic to human behavior levels; a complete catalog of cancer etiologies; anti-gravity; complete mapping of genomics to disease prediction; proof of sentient life on other planets; and an understanding of the uni-directionality of time.

Asked to predict which *technologies* would have the biggest impact in the next 35 years, participants chose Artificial Intelligence (69), Big Data Analytics (55), and Biotechnology (54). Robotics and Medicines were two areas that followed closely in the polling.

In response to "What advances will require more than 35 years," top answers were reverse-engineering the human brain, commercial stations in space or on other planets, and reversal of the effects of climate change.

In open-ended responses, respondents expressed that in addition to sci/tech breakthroughs, the will and wisdom to implement them appropriately, and the rate of diffusion of the implementation across populations is very important. In this fourth survey, when asked to predict which *business* sectors would have most development in the next 35 years, participants chose Robotics (57), Biotechnology (54), and Energy (51). Their remarks about business developments in the next 35 years included:

> "Large corporations will disperse into networked organizations; R&D will be globalized and virtual."
>
> "Sharing economy and other new business models may emerge and even become the new paradigms."
>
> Healthcare via "a combination of diagnostics, sensors, robotics aids, independent living assists - should be a major growth area for business."
>
> "Autonomous production of energy by households."
>
> "A return of faster than sound aircraft, made possible by new materials."
>
> "I'm almost certain that the most change we will see in the next 35 years will be in entirely new industries that we cannot even imagine. Think back to 35 years ago - positions like 'social media manager' and 'machine learning engineer' were nonexistent."

The forecasting/policy experts' *dream products* for the next 35 years fell primarily into the categories Alternative Energy products, Space Travel, and Robots. Their free-form answers to the dreams/needs question appear in Appendix I. The forecasting/policy experts were more skeptical about medical futures than were the magazine readers. This could be because, as on expert remarked, the important issue is not always the technical advance, but the feasibility and speed of delivering it to the intended customers. (Or, as a 2018 *Fast Company* article[7] suggested, "The big question is whether the productivity gains from automation will offset the loss in demand from workers whose jobs have been eliminated by it.")

Responses to the first three surveys spurred additional questions. Having established a frame of reference with the scaled-response questions (which were substantially the same as those in the earlier surveys), we posed the additional queries to the F&P experts, allowing free-form replies.

6.1. Evaluation of the HBR, science, and nature survey results

Most forecasting and policy (F&P) respondents indicated general agreement with the earlier results. Typical comments were: "plausible," "reasonable," "My answers were similar," "My own responses matched the above findings very well and I agree that the identified forecasts are very realistic." However, cautions were noted:

> "It's not surprising that healthcare/biology/medicine are at the top of most lists because that's what the majority of scientists do and where the majority of funding and hype are located."
>
> "Areas are related; a system approach is needed."

Others remarked that respondents are stuck in a mental paradigm of the present, that more creative and off-the-wall responses would have been more helpful.

There was an argument for the importance of advanced materials: "To the extent that medicine is important it will be more because of advanced materials and devices than advances in science…. Energy, on the other hand, is showing slow and steady gains…. A lot of this is due to advances in materials."

6.2. Optimism, pessimism

Some F&P respondents saw the more promising possibilities:

"The steady market acceptance of renewable and other non-CO_2 producing energy sources and energy storage, coupled with increased energy efficiency in all sectors, will slow and eventually halt the growth of greenhouse gas buildup."

"Even though current evidence suggests we have recently taken a few steps back when it comes to moving towards a more open and tolerant world, I remain optimistic about the future."

They were slightly outnumbered by those with the opposite view:

"Genetic enhancement could create post-human enclaves, greatly exacerbating inequality. We must get climate change under control or similar inequality will lead to strife, possibly war."

"There is likely to be increased social turmoil as automation advances. The political situation is likely to deteriorate."

"I'm on the 'danger side.' Technologists are not broad enough in their thinking to be aware of and concerned with the dangers of what they are doing."

[7] http://feedproxy.google.com/~r/TheLow-down/~3/UXx003vWgKk/how-automation-demographics-and.html?utm_source=feedburner&utm_medium=email

Table 4
Top three expected technology and industry convergences – F&P expert survey.

Areas of expected technology convergence	"Business areas most likely to combine, perhaps through mergers and acquisitions"
1 Artificial intelligence with advanced analytics of big data	1. Agriculture/food with biotechnology
2 Artificial intelligence with Robotics	2. Biotechnology with diagnostics
3 Synthetic biology/genetic engineering with Medicine and health	3. Automotive with robotics

And some straddled the fence: "There will be a religious revival in the next 30 years - not clear whether that will be tolerant or not - history would say no."

6.3. Social, economic, environmental, and political changes

What social, economic, environmental, and political changes in the next 35 years will do the most to create, change, or grow markets; stress our social fabric; or demand technological solutions? The top three answers were climate change, aging populations in rich countries, and [global] population growth. These were far ahead, in polling, from the 4th to 6th top answers, which were migration, poverty, and new alliances and defense blocs.

6.4. Convergence

45% of HBR respondents agreed or strongly agreed that the industry they work in will converge with another industry within ten years, as a result of sci/tech advances. The F&P expert survey asked more specifically about technology and industry convergence in the next 35 years. Top expected combinations are shown in Table 4. Overall, the sector most expected to combine with another (i.e., any other) is Robotics, followed by IT/Software, and Pharmaceuticals.

6.5. Views of the long cycles

Kondratieff cycles, or K-waves in the economy appear to be due to technological revolutions. These revolutions expand the economy. When it becomes more profitable to exploit these new technologies than to further push the technology frontier, the K-wave crests. In turn, the profits from the new technology fall to the level of profits from other commodities, and the economy, fresh out of new ideas, contracts. See Grinin et al. (2012); Focacci (2017). The entire cycle has historically taken 60 years. Respondents to the fourth survey were asked whether in the year 2052 we will be on the down-slope of the sixth K-wave. Respondents were surprisingly agnostic: 43 had no opinion, 23 agreed, and 15 disagreed. A follow-up item, "2052 and surrounding years will be accompanied by the burst of innovation that is typical of down-waves," drew 14 disagreements, 38 neutral, and 28 agreements.

6.6. Action recommendations for businesses

The first step for business leaders, said a number of respondents, is to be well-trained to systematically envision possible futures. Other recommended steps:

Focus more on resilience and less on short-term profit.

Be knowledgeable about business model innovation.

Cultivate technological absorptive capacity.

Most large-scale corporations will break down into networked organizations. This will happen naturally, but they will need to begin the financial transition in the near future.

Always look for the underlying needs of humans and whether and how these breakthroughs satisfy them.

Create visions, strategies, lines of evolution, and a culture in which dreaming and working on dreams is part of a job.

6.7. Implications of survey results for policy makers

Despite some skepticism, most saw the need for government intervention; only a tiny minority suggested that free markets can deal effectively with long-term and systemic problems, or volatile issues of social equity. Says one of the majority, "Government funding may need to supplement the private sector, because environmental innovation is socially desirable but difficult to monetize."

7. Discussion: Gap analysis

In this section we examine the many between-group differences revealed through the surveys that may suggest policy actions.

7.1. Businesspeople vs. scientists

Survey results revealed gaps between *Science* and *Nature* respondents on the one hand, and *HBR* readers on the other. The biggest gaps between business and science respondents appeared in expectations for advanced materials (rated much more highly by business people) and for augmented reality (rated much more highly by science and technology people).

The F&P experts commented on this gap; They largely took the side of the businesspeople, noting that more scientists are involved in information and communicate tech (ICT) areas than in MSE (Materials Science/Engineering), that advanced materials are a general-purpose technology essential for many new and improved products, and that augmented reality will remain a niche product for some time to come, competing with full virtual reality for dominance in varied domains. One F&P expert remarked, "This is a very interesting result on which we can capitalize to build interdisciplinary research that benefits different interest groups."

7.2. Business vs. forecaster

Business people and forecasting and policy (F&P) experts named the same top three breakthrough-prone science disciplines: Biological sciences, Medical sciences and Computer science. F&P experts have lower expectations in Mathematics and Earth sciences than business people, but higher hopes for Chemistry and Astronomy.

When asked to forecast the technology that will have the biggest impact in the next 35 years, both groups of participants granted the first spot to Artificial Intelligence. Advanced analytics of big data and Synthetic biology/genetic engineering also enjoy high expectations from both groups. All the technological areas earned higher expectations from business people than from forecasting and policy experts, perhaps reflecting laypersons' perception of the high momentum of recent decades' advances.

Compared to the F&P experts', business people's technological forecasts showed little variations across categories, in terms of numbers of votes. That is, business respondents tended to award the same number of votes to all technology categories. Again this is possibly due to the latter's technological naivete; they might have been guessing.

Space travel received above average rating from business respondents, but is near the bottom in the forecasting experts' list.

Computers/Robots/Nano and Healthcare dominate both groups' "dream products." However, F&P experts see more need in Energy and less in Transportation, compared to business people.

7.3. Sub-group differences among scientists/engineers

To look at differences in responses by scientists' career stage and by geography, we classified Healthcare professional, Laboratory Director, and Research Directors as "senior," and Technicians, Research Assistants, and Other as "junior." Geography was represented by continent of residence.

Respondents in more senior positions believe most scientific advances will come from Biological Sciences. Their juniors think more advances will come from Computer Science. Technicians/Assistants chose Medical Science and Others chose Biological Science. There were no notable geographic differences on this question.

As regards expectations for new technologies, no seniority or geographic differences were noted.

Asked what business areas will be most impacted, the majority chose Biotechnology. However, Lab Directors favored Energy, while Healthcare Professionals chose IT/Software. Asked which business sectors will face the future's biggest challenges, no seniority nor geographic differences appeared. Answers varied, however: Research directors chose "Biotechnology" and "Energy"; Technicians chose "Energy"; and Others chose "Agriculture."

7.4. Expectations vs. needs

Computers/Robots/Nano and Healthcare are forecasted to reflect highest needs. Likewise, Biological sciences and Computer science acquire highest expectations for breakthrough in science. Artificial Intelligence (AI) is seen as the most influential enabler for both.

Although few respondents mentioned Materials as a high-need category for the next 35 years, Material science was ranked 4th as the discipline most likely to show breakthrough discoveries.

7.5. Social vs. business impacts

HBR respondents were asked about the anticipated social impact and (in a separate question) the expected business impact of the listed technology advances. The top three social impact areas were "food for the world," "curing cancer," and "reversing climate change." The top three business impact areas were "food for the world," "renewable energy," and "secure Internet."

The top three gap areas in which business impact is greater than social impact were robots with AI, virtual reality, and space stations. The top three gap areas in which social impact is greater than business impact were curing cancer, pandemic preparedness, and genetic modification of humans. (Food for the world, and reversing climate change, were fourth and fifth on the latter list.)

We find these results to be telling. Most of the latter list implies possible existential threats to humanity. The survey says that business will not be prepared to deal with them; social enterprise must step in, and/or other basic changes to the economic system will be required. As for the former list (business impact greater than social impact) we see that business people expect space exploitation to be largely privatized, and they do not believe an AI "singularity" will transform society.

7.6. Needs vs. global funding trends

Global R&D funding trends, 2014–16 (abstracted from *R&D Magazine* Editors 2016) show:

- Life Sciences: Up 1.5% to 169.3 billion USD.
- Aerospace: Up 6% to 30.4 billion USD.
- Advanced Materials & Chemicals: Up 2.1% to 44.4 BUSD.
- Info & Communication Tech: Up 5.5% to 204.5 BUSD.
- Automotive: Up 7.7% to 94.2 BUSD.
- Energy: Up 5% to 23.0 BUSD.

The large increases of global R&D funding for Automotive and Info & Communication Tech (7.7% and 5.5%, respectively) seem to be on par with our respondents' perceived high demand for Computers/Robots/Nano products.

Despite being among the areas with highest perceived need in the future, Life Sciences is enjoying only a small rise in funding.

Though the experts name Energy as a high-need category, Energy receives the lowest budget (23.0 BUSD) currently, and shows only a middling funding increase 2012–16.

8. Cautions in interpreting the data

We looked for own-discipline bias in the responses, but did not find much. Scientists working in biological sciences were disproportionately likely to predict the most advances and impacts in biological sciences, synthetic biology, genetic engineering, and agricultural business. This effect was not found among respondents working in other scientific areas.

These global data hide tech leader/follower country effects. The USA is ahead in most fields, but shares automotive primacy with Germany and Japan (*R&D Magazine,* 2016). We have asked scientists, forecasters, and business people about science, technology, and business prospects, but (except where engineers happen to be members of our surveyed groups) we did not specifically query engineers. Nor did we explicitly target military respondents, and this should be a priority for future surveys. (In this vein, the US General Accounting Office (2018) identifies eight "trends affecting government and society," mainly geopolitical trends that our survey respondents did not focus upon.)

Several respondents thought the surveys paid insufficient attention to social equity. In particular, one respondent remarked that we have not attended sufficiently to the workforce. "Without jobs," the respondent wrote, "there will be political strife in all areas."[8]

To gain access to the readers of the cooperating magazines, the present authors had to relinquish strict control of the sampling plan and questionnaire design. This appears to be an unavoidable hazard of inter-organizational collaborative science.

Prediction is error-prone ("especially about the future," as Neils Bohr remarked), and long-term funding is uncertain in every country.

9. Summary

In the three surveys, consensus was strong on the areas of science anticipated for breakthroughs. Less consensus appeared in forecasting technology progress and even less on business progress.

The thousand *Harvard Business Review* respondents indicated that the greatest potential for breakthrough discoveries in the next 35 years would occur in Medical Science, Computer Science, Biological Sciences, and Material Science. Business-centric respondents, including the management consultants group, believed that the Medical Science area would have more breakthroughs than the Computer Science or Biological Science sectors.

Some questionnaires included additional questions about innovation. Most *HBR* respondents (93.3%) strongly believed that in today's rapid economy cycle, innovation must be a continuous process embedded in business. *Harvard Business Review* respondents said the top drivers of innovation in their organizations were to improve customer experience (52.0%), to develop new streams of revenue (42.0%), and to

[8] In fact we did collect opinion data on future workforce, but omitted it here in the interest of making a paper of reasonable length.

leverage opportunities in niche markets (25.5%). On the other hand, when asked the greatest barriers to innovation in their organization, participants cited time insufficiency due to the full-time attention necessary to fulfill core business needs (51.0%), a lack of resources (46.2%), and collaboration deficiency between functional areas or organizational divisions (44.3%). These barriers will stress companies' ability to rise to the challenges highlighted in this paper.

In addition, over three-quarters of respondents (81.9%) strongly believed governments should provide funding, incentives, and tax breaks for research and innovation that solves human, social, and environmental problems.

When asked about which sectors would have the biggest challenges in the next 35 years, the participants in the both surveys anticipated that the *Agriculture* sector would face the biggest challenges within the next 35 years (*Nature*, 45%); *Science* (49%). The second and the third were slightly set apart in the two surveys: *Nature* survey respondents thought that *Energy* sector would be the second most likely business sector facing the biggest challenges in 35 years (43%) and *Education* sector came as the third most likely facing the biggest challenges in 35 years (32%). *Science* survey respondents thought that *Healthcare* sector would be the second most likely business sector facing the biggest challenges in 35 years (47%) and *Energy* sector came as the third most likely facing the biggest challenges in 35 years (44%).

A plurality of respondents saw a sweet spot in the application of computer science to medicine/biological sciences – agreeing with Steve Jobs, who said, "I think the biggest innovations of the 21st century will be at the intersection of biology and technology. A new era is beginning." The application of big data analysis to systems biology will go beyond what Jobs foresaw.

On the technology side, there was also overall consensus on Biotech, Medicine, and AI. *HBR* readers see in 35 years space travel, energy and biotech, but in a ten-year horizon also AI, medicine, and biotech/synthetic biology. The forecasting/policy experts focused on AI, biotech, and Robotics. The forecasters, interestingly, are more skeptical about progress in medicine compared to the scientists and business people.

As for business, general agreement was very similar: Biotech (selected by all as among the top three), Energy (selected by all as top three) and then IT/robotics. Conclusion: The future will be bright for biotechnology/synthetic biology and AI/robotics, and for their intersection.

Expressed dreams and needs fell into areas of Energy, Transportation and Medicine/Longevity as a consensus from all surveys. It is interesting that there was no expressed demand for weapons, communications, or AI/computing. The latter might be seen as odd, since cryptography, a sub-category of computing, may prove essential to the secure internet desired by many respondents. Yet the result accords with a recent analysis demonstrating that advancement in communications, and AI/computing is already very strong (Betz, 2018). We surmise that needs and wants in the two fields are apparently well covered, in contrast to areas such as health and longevity, and that non-military persons (undoubtedly the majority of our respondents) do not tend to think about weapons of war.

Overall, we found that the combination of medical, biomedical, and biotech advances with developments in artificial intelligence will have the greatest impact on business and society in the next 35 years. Progress in energy and transportation, both resting on new advanced and sustainable materials, will accompany this development, subject to research funding and workforce preparedness. Surviving companies and industries will flexibly plan and respond to the inevitable convergences.

In addition to the "action recommendations for businesses" noted in §6.6 above, five key management take-aways, for positioning a company for the future can be extracted from this study:

1) A golden era for medicine is dawning, empowered by new breakthrough technologies and the digitalization of medicine. Investments in this area are highly likely to pay off in the long term.
2) Biological sciences/synthetic biology is the new enabling science that will exhibit its enormous disruption potential in the coming decades (as digitalization currently does). Carefully watch new technologies emerging from this science area.
3) Agriculture will face major challenges in the coming years. It is a field where innovation will certainly pay off.
4) Fields identified with high expected social impact should develop into commercial or social entrepreneurship opportunities, and therefore are investment opportunities. They are: Ensuring the nutrition of a growing world population, curing cancer, reversing the effects of climate change, and improving preparedness for a new pandemic threat.
5) Customers want especially new products in two areas: healthcare and transportation.

Naturally these recommendations are of interest only to companies that can overcome "short-termism" and see relevance in a 35-year planning horizon.

Given the number of "science fiction" technologies that have become reality, we have no doubt that our expert respondents' technology predictions are generally on target. It is the uses to which people put the technologies that is much more subject to uncertainty. For example, who would have imagined that computers would be used more for communication and data storage (and for looking at cat pictures on Facebook) than for calculating? The Internet was commercialized as a 1-way flow of content. Unexpected demand for 2-way interaction led to Web2.0. It is these emerging uses that really shape our lifestyles.[9] It will take much business imagination to anticipate them.

Desiring to know whether a study like this says anything definite about the future, we asked the forecasting and policy experts, "Do you believe that widespread, shared perceptions about the future, like those revealed [in responses to the first three surveys], are instrumental in creating the future?" The answer was overwhelmingly (36 to 12) "yes." Respondents sensibly added that it is "yes" in broad outline; details are much less predictable or achievable. They emphasized that black swans are to be expected.

Acknowledgements

This work was funded by Merck KGaA Darmstadt Germany.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.techfore.2019.04.005.

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[9] And vice versa. Two-way video telephony was introduced in the 1960s. It was shunned because that era's potential users felt they must fix their hair and make-up before answering the phone. Subsequent decades' less formal lifestyles made Skype video calling (for example) acceptable and desirable.

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